

**GLAST**

# **Inclination Trade Report**

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**August 1999**

# 1 Introduction

The South Atlantic Anomaly (SAA) is a problem for the GLAST mission because it prevents the Observatory from viewing the celestial sky when the Observatory is passing through the SAA. For GLAST in circular low earth orbit, the outage due to the SAA can be minimized by reducing orbit inclination and altitude, either together or separately, and it can be avoided completely by reducing orbit inclination to near zero. In this report it is primarily the benefits and costs of orbit inclination changes that are studied, with different inclinations being achieved through launch vehicle selection or launch site location. This is done on the hypothetical basis that these inclinations would be available to GLAST if additional money were available. There are several alternatives for lower inclinations, and these are evaluated against the baseline mission of 28.5-degree inclination. Each alternative requires different launch services to put the given mass of the payload into its respective orbit. Note that reducing mass of the instrument is not considered to be an option.

The method of minimizing the SAA outage by maintaining a reduced altitude is dealt with separately and appears in Appendix 3. The ability to maintain a reduced altitude requires the use of an on-board propulsion system. Since this method turns out to be not feasible, cost and reliability are not treated. This mini study also may be of interest to those who are interested in improving mass margins by trying to take advantage of the fact that greater mass can be launched to lower altitude.

In the following sections, the alternatives are described first. This is followed by analyses that characterize the charged particle environment, the uniformity of sky coverage, and the required capabilities of launch vehicles. The alternatives are then evaluated in terms of performance, reliability, availability, and costs. Measures of effectiveness are developed and subjective judgements are applied for the valuation of these criteria. A summary of the evaluations is given, and the conclusion is stated.

Several people contributed to this study, some unknowingly. Seth Digel performed the sky uniformity analysis. Steve Tompkins provided cost and availability information on communications and ground stations. John Leon provided the reliability and cost data on launch vehicles, and Frank Stone looked into ways and means of purchasing foreign launch vehicles. The value judgements that are used in the evaluation of alternatives, however, are my own.

## **2 Description of Alternatives**

### ***2.1 Baseline 28 Degree Inclination***

The baseline mission uses a Delta II 7920 launch vehicle to place the GLAST observatory in a circular orbit at 550 kilometers and 28.5 degree inclination. The launch site will be the eastern launch range at Cape Canaveral. This launch vehicle has a capability of 4500 kg for this orbit, which just exceeds the current mass allocation of 4240 kg for the GLAST observatory.

In this orbit the Observatory encounters the South Atlantic Anomaly (SAA). The trapped protons in this region cause the photomultiplier tubes (PMTs) that monitor plastic scintillators to saturate and possibly incur damage. To avoid this possibility, the PMTs are turned off by turning off their high voltage power supplies. As a result approximately 25% of this orbit is unavailable for viewing. This does not create a blank spot on the celestial sky, however, because the SAA rotates with the Earth and the orbit precesses with respect to the Earth. Instead, the result is a portion of the sky that is viewed less often than the rest of the sky, and it will take longer to view this part of the sky to the same level of sensitivity as the remainder of the sky. In addition the inertial viewing of any transients or of pointed observations will be interrupted while the Observatory is in the SAA.

### ***2.2 Option for 15 Degree Inclination***

In order to get to an intermediate inclination of 15 degrees from a launch site that is at higher latitude, it is necessary to perform a plane change. A plane change from 28.5 to 15 degrees requires a larger launch vehicle than the Delta II, which has practically no capability for performing a plane change for the mission payload. An Evolved Expendable Launch Vehicle (EELV) that promises greater capability at a moderately higher price would be a logical alternative. The main benefit of a 15-degree inclination is to reduce the size of the SAA encounter by about half. But all of the disadvantages of a higher inclination remain.

### ***2.3 Option for 5 Degree Inclination***

An option for a 5-degree inclination exists because it can be achieved directly by the Ariane 40-3 from the Kouru launch site at 5.1 degrees, and because it is within the capability of two of the larger domestic vehicles from a launch site at 28.5 degrees. While 5 degrees doesn't completely avoid the SAA, it does provide much reduced exposure to it.

### ***2.4 Option for 0 Degree Inclination***

There are two ways of getting to a 0-degree inclination. The first way is with the Ariane, performing a plane change from its 5-degree launch site. Since the Ariane 40 is marginal for the GLAST payload to begin with, a plane change of even a few degrees would require the next larger vehicle in the Ariane family, the Ariane 42P. The second way of

achieving a 0-degree inclination is with the Zenit 3SL vehicle that is launched at 0 degrees from a converted oil platform on the equator. Either of these methods will completely avoid the SAA.

## 3 Analyses and Results

### 3.1 Radiation Environment

The radiation environment for low earth orbit was analyzed using CRÈME 96 to evaluate trapped and non-trapped components for the different orbit inclinations. Admittedly, the CRÈME model is somewhat inaccurate at low altitude and low inclination where the spatial gradients are high for the SAA, but it should be adequate for making relative evaluations.

Plots of the orbit averaged radiation environment are shown in Appendix 1. The trapped components appear below 1000 MeV in energy and consist primarily of protons, while the non-trapped components are above 1000 MeV and consist of Galactic Cosmic Rays (GCRs). As inclination decreases it is seen that the number of trapped protons also decreases at their higher energies, while the geomagnetic cutoff of GCRs increases from 1 to 4 GeV. This causes the non-trapped GCR flux to also decrease with inclination.

CRÈME provides peak integral fluxes of the trapped components. (The integral is over all nucleons and all energies in the SAA where the fluxes are greatest.) These are plotted vs. inclination in Figure 3-1 to give a measure as to how much the SAA outage is reduced when changing inclination. This plot is simply the cross-sectional profile of the SAA along a meridian passing through the center of the SAA to the equator. A contour plot of the SAA is shown in Figure 3-2. The CRÈME model has the trapped fluxes disappearing at less than 1 or 2 degrees inclination. At these inclinations there is no longer any need to turn off PMT high voltage supplies, and there is no penalty due to the SAA to observing efficiency and exposure uniformity.

The non-trapped components that exist throughout the orbit need to be integrated manually. This was done crudely for the first 8 nucleons and resulted in a GCR flux of 157 particles/m<sup>2</sup> sr s at 28.5 degrees, 110 particles/m<sup>2</sup> sr s at 15 degrees, and 100 particles/m<sup>2</sup> sr s at 5 degrees. The model indicates no particles at 0 degrees.

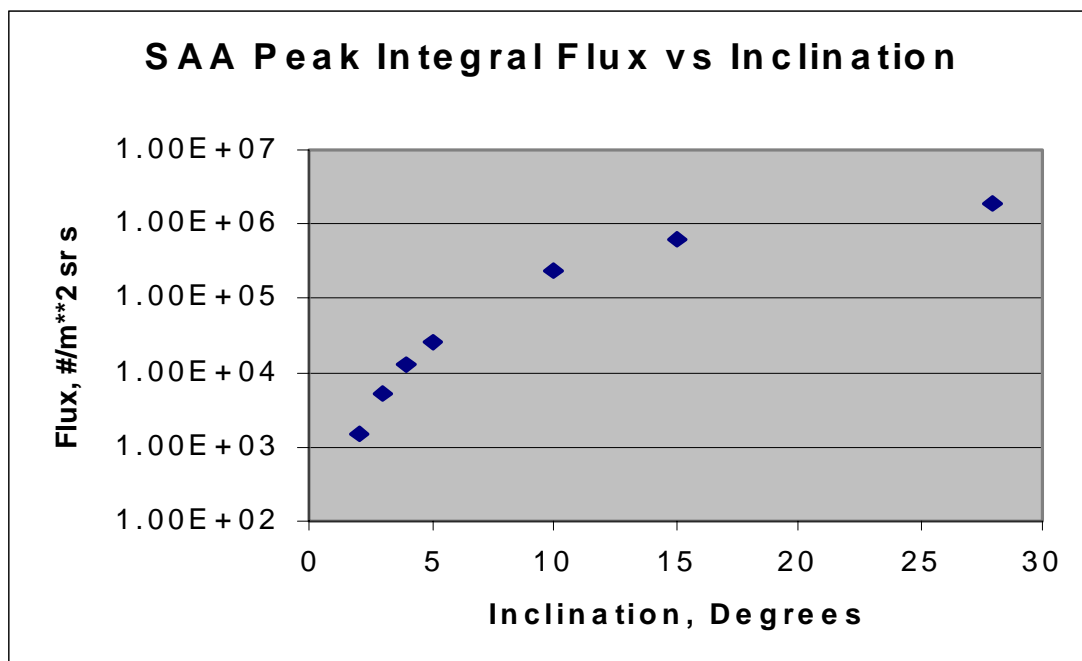


Figure 3-1 Radial Cut Through the SAA (From Equator toward SAA Center).

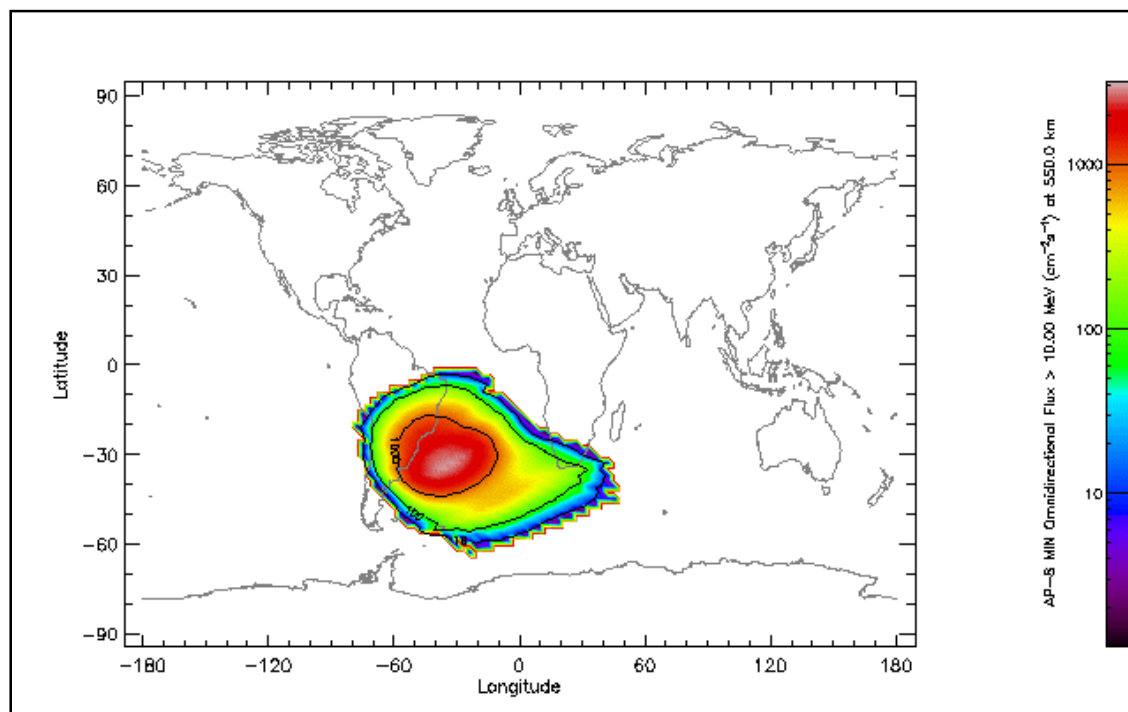


Figure 3-2 Contour Plot of the SAA.

### 3.2 Sky Coverage

Seth Digel evaluated sky coverage vs. inclination<sup>1</sup>. Seth used the SAA boundaries that are used by GRO at 450 km, 28.5 degrees, circular orbit, and showed that there is an asymmetry in exposure due to the SAA in the Southern Hemisphere. Since the SAA grows with altitude, the SAA boundaries will be at least as large for GLAST at 550 km.

The uniformity of sky coverage increases as inclination is reduced because less of the orbit passes through the SAA. The best uniformity, of course, is obtained when the SAA is avoided altogether, as at zero degrees inclination.

In addition to evaluating exposure uniformity, Seth verified that there are no inaccessible regions of the sky, or holes in coverage, at either inclination of 28 degrees or of 0 degrees.

### 3.3 Launch Vehicle Capabilities

On the basis of using the minimum capability needed to achieve the desired orbit, different inclinations require using different launch vehicles. For inclinations that are at or near the latitude of the launch site, no plane change is necessary, and the launch vehicles of choice are:

28.5 degrees	Delta II	4500 kg
5 degrees	Ariane 40-3	4300 kg
0 degrees	Zenit 3SL	8000 kg

For inclinations that are lower than the launch site latitude, the launch vehicle must be capable of performing a plane change. To achieve 0 degrees inclination from latitude of 5 degrees, the next larger Ariane, the Ariane 42P with a capability of 5400 kg is needed. To achieve lower inclinations from latitude of 28.5 degrees, one needs to determine which domestic launch vehicles have the necessary excess velocity. At 550 km, it takes 132.4 m/s per degree of plane change. The excess velocities needed for different inclinations from a 28.5-degree latitude are:

Inclination	28.5	20	15	10	5	deg.
Excess Velocity	0	1.125	1.787	2.449	3.111	km/s

From the Delta IV Payload Planners Guide<sup>2</sup>, the Delta IV-M has an excess velocity of 2.0 km/s and can therefore achieve an inclination of about 13 degrees, while a Delta IV-M(5,4) with an excess velocity of 3.15 km/s can achieve about 4.5 degrees.

<sup>1</sup> The Effect of Orbit Inclination on the Exposure for the GLAST Sky Survey, S. Digel, USRA/GSFC, 26 May 1999 <http://www701.gsfc.nasa.gov/glast/engn.htm>

<sup>2</sup> Delta IV Payload Planners Guide, MDC 98H0064, The Boeing Company, September 1998, <http://www.boeing.com/defense-space/space/delta/delta4/guide/delta4.pdf>

## 4 Evaluation of Alternatives

In this section of the report, the alternatives are evaluated in terms of performance, reliability, availability, and cost. The priorities of these objectives, or criteria, as they relate to choosing the best inclination, determines the weight that is distributed to sub-criteria. It may be thought that performance is everything on the one hand, or that cost is everything on the other, depending on one's point of view. But it's not O.K. to fail (reliability), and it doesn't do any good if "you can't get there from here" (availability). So at this point, the criteria are equally weighted, as there is no basis for regarding any one more important than any other. Each sub-criterion has a measure of effectiveness that is indicative of the contribution of value or utility of those sub-criteria. One never knows just exactly what that value or utility is, just that one has more or less of it. Values/utilities are all on a scale of zero to one and are each a function of the appropriate measure, sometimes as a percentage of the maximum measure, other times in proportion to a normalization of the measure. One method of evaluating alternatives is by constructing all of the value/utility functions for the measures of effectiveness, distributing weights and calculating scores, as with a spreadsheet. A similar method, which is used here, is the use of the decision making tool, EXPERT CHOICE. This tool is based on the Analytic Hierarchy Process (AHP) and allows for valuations of direct data entry as well as by deriving them by pair-wise comparisons of subjective judgements. A verbal scale is most useful for judging the relative importance of criteria. The verbs on this scale that is used below are "equal", "moderate", "strong", "very strong", and "extreme". Since the tool merely reflects what one puts into it, the rationale for weighing the relative importance of similar sub criteria and the valuation of them will be presented first, then followed by the results of using the tool.

The reader may agree or disagree with the judgements of relative importance. Any reader input is easily combined with those that are presented here and would serve to move the study toward a consensus.

### 4.1 Performance

There are two measures of performance that are affected by choice of inclination, low instrumental background and viewing efficiency. The relative importance of these is judged, respectively, as a tradeoff of data quality versus data quantity. For this mission, one would say that low background is moderately to strongly more important than viewing efficiency, thereby preferring data quality over quantity.

#### 4.1.1 Charged Particle Background

Although the charged particle environment for GLAST consists of two primary components, trapped and non-trapped, only the non-trapped component contributes to instrumental background, because the instrument is effectively turned off when exposed to the trapped component. The evaluation measure of reduced inclination is given by the reduced GCR flux:

Inclination	28.5°	15 °	5 °	0 °
GCR flux, #/m <sup>2</sup> sr s	160	110	100	-

The scale of goodness is toward lower inclinations with less GCR flux.

This valuation includes any scientific benefit as well as any cost benefit due to reduced charged particle background. That is, no attempt is made to value separately the benefit of reduced veto rate on power, for example, or the benefit of less GCR contamination that results in fewer misidentifications and less data transmitted to the ground and processed. It's the total value of reduced GCR flux that is valued here.

### 4.1.2 Observing Efficiency

Observing efficiency is a measure of how well use is made of the finite mission life for measuring gamma rays. There are a number of factors that contribute to observing inefficiency. Among these are effective loss of field of view, time spent viewing the Earth, and time in the SAA. Since loss of observing time in the SAA is the relevant factor for this study, the SAA outage alone is taken as the metric for the benefit of reduced inclination. Over the course of many orbits, this may be estimated from the ratio of the area enclosed by the SAA boundary to that of the orbit. Using a box of 30 degrees by 135 degrees, the areal ratio will scale linearly as the 30-degree dimension is reduced to 15 degrees and 5 degrees. The SAA efficiency (1-inefficiency) estimated in this way is

Inclination	30°	15°	5°	0°
SAA Efficiency	80%	90%	97%	100%

The valuation of increased observing efficiency is taken as a percentage of the maximum measure, which in this case is the efficiency data directly.

## 4.2 Reliability

There are two reliability concerns that are addressed in the next two paragraphs, one for the instrument, the other for the launch vehicle. Launch vehicle reliability is weighed much more heavily than instrument reliability because the instrument reliability risk can be mitigated and would probably be only degraded by a failure, while a failure in the launch vehicle is probably a mission ending failure.

### 4.2.1 Instrument Reliability

The need for power cycling the PMT power supplies once per orbit due to the SAA poses a reliability concern that needs to be addressed in instrument design. At 550 km there are 15 orbits per day<sup>3</sup>, and a 5 (10) year mission will incur 27,275 (54,750) cycles if every orbit goes through the SAA boundary. Techniques for mitigating the risk of failure due to cycling would include selection of parts with latch-up immunity and plenty of design margin, partitioning the system to limit the extent of a failure, and providing redundancy to maintain the desired level of operability in case of a failure. Although these techniques may be used for reasons other than the SAA, with respect to the SAA itself, these techniques would be needed for any orbit that passes through the SAA. Even though risk probably decreases with inclination as fewer orbits pass through the SAA, the implementation decision is a go, no-go decision, and so orbits with SAA exposure would get the risk mitigation treatment, while an orbit that misses the SAA would not. The

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<sup>3</sup> Space Mission Analysis and Design, 2<sup>nd</sup> Edition, W. Larson and J. Wertz Ed.

value of a zero degree orbit, therefore, is close to 1 for risk mitigation, while higher inclinations are valued at practically 0.

### 4.2.2 Launch Vehicle Reliability

Launch vehicles come with different pedigrees of reliability, and this is particularly important, as a failure in the launch vehicle is probably a mission-ending failure. Families of launch vehicles, like the Ariane and Delta II have been around for a long time and have established reliability figures. When the most recent 20 launches are considered, a newer vehicle like the Zenit 3 can be included in the comparison. The EELVs – Atlas IIIs, Delta IVs – haven't yet established a track record but can be expected to have several of their initial launches accomplished by the time GLAST would be launched in 2005. Still, any new vehicle can also be expected to have problems initially, and it certainly wouldn't have the reliability rating of the older, more established vehicles. Using the reliability data that is currently available (Oct, 1998) for the most recent launches in the different families, the vehicles compare as follows:

Vehicle	Zenit 3SL	Ariane 40-3 (42P)	Atlas V	Delta IV- M(5,2)	Delta IV-M	Delta II
Latitude, Deg.	0	5	28	28	28	28
Inclination, Deg.	0	5 (0)	5	5	15	28
Reliability	17/20 = 85%	20/20 = 100%	TBD	TBD	TBD	20/20 = 100%

At the present time, the most reliable launch vehicles are those that provide direct launch to orbit inclination, Zenit 3, Ariane 40, and Delta II, while those that are needed to perform a plane change, Delta IV or Atlas V, are the newest and will probably be of less reliability and higher risk at the time of launch.

For purposes of valuation, we assume that the TBD for 5 and 15 degree inclination reliability is not zero, but some number like 50%. Reliabilities are then valued directly in terms of percentages.

## 4.3 Availability

There are two concerns of availability when considering low inclination orbits for GLAST. One is the availability of low latitude ground stations with coverage for direct communications. The other is the availability of a launch vehicle that can provide the orbit. In the following paragraphs it will be apparent that the launch vehicle concern is by far the greater, and that it deserves a relative weighing of very strong.

### 4.3.1 Availability of Ground Stations

The lower inclination orbits (0, 5, 15 degrees) all call for the availability of low latitude ground stations with both S-band and X-band capabilities. Although these are not

entirely available today, their availability in the GLAST operational time frame is not out of the question. The table below indicates present and future capabilities of ground stations that can provide coverage for low inclination orbits.

	Existing Ground Stations				Future Ground Stations		
<b>Location</b>	Malindi	Hawaii	Mayaguez Puerto Rico	Diego Garcia	Guam	Brazil	India
<b>Latitude</b>	3 Deg S.	19 Deg N.	18 Deg N.	7 Deg S.	13 Deg N.		
<b>Owned By</b>	Italy	USN	NASA	USAF	USN		
<b>Operated By</b>	Italian Govmt	Universal Space Network	Johns Hopkins U. Puerto Rico	USAF	USN	Allied Signal	Allied Signal
<b>Capability</b>	S/X - Band 10m	S-band 13m	S-band, T/R X-band, 4.5m R.	S-band 10m	5m	5m	5m

Since existing ground stations can support the higher inclination orbits of 15 and 28.5 degrees, these are valued more highly than the future ground stations that are needed for the lower inclination orbits of 5 and 0 degrees.

#### 4.3.2 Availability and Approval of Launch Vehicles

Although the foreign launch vehicles made by France (Ariane) and by Ukraine (Zenit) are included in this study as energy efficient and cost efficient means of getting to low inclination orbit, it turns out that these vehicles can not be purchased with U.S. dollars for NASA-related missions. This is established in the email messages in Appendix 2. These vehicles are available to GLAST only if an exchange of benefits can be arranged between the U.S. and the respective foreign space agency.

The newer vehicles, the Delta IVs and Atlas V, are expected to be available in the next few years and in time for GLAST, should GLAST be able to obtain approval to use them. The GLAST mission will probably be classified in risk category 3<sup>4</sup> as mission critical to implementation of NASA's Strategic Plan, and requiring a launch vehicle "with a demonstrated flight record consisting of a series of consecutive successful launches of a common vehicle configuration (i.e., 95-percent reliability @ 50-percent confidence level)". The newer vehicles may not fit in this risk category. In addition, if one of these

<sup>4</sup> NASA Policy Directive, NPD 8610.7, Launch Services Risk Mitigation Policy for NASA-Owned Or NASA-Sponsored Payloads, February 4, 1999

[http://nodis/Library/Directives/NASA-WIDE/Policies/Program\\_Management/N\\_PD\\_8610\\_7.html](http://nodis/Library/Directives/NASA-WIDE/Policies/Program_Management/N_PD_8610_7.html)

launch vehicles were required only because of the desire to get to low inclination, one would expect that a strong case for a low inclination orbit would be needed, such as not being able to achieve one or more science objectives.

Note that the above reliability statement will also apply to any successors to the baseline launch vehicle.

The baseline launch vehicle for 28.5 degrees is therefore valued much more highly than the other launch vehicles that have little or no chance for this mission.

## 4.4 Costs

As with the other criteria there are two concerns, in this case, costs of ground stations and costs of the launch vehicle. And, as with availability, the costs of the launch vehicle are strongly more important. In this case, the differences of launch vehicle costs are many times the cost differential of the ground stations.

### 4.4.1 Costs of Ground Stations

The communication costs of existing and future ground stations that could potentially support the GLAST mission in different inclinations are shown in the table below.

	Existing Ground Stations				Future Ground Stations		
<b>Inclination Coverage</b>	0 Deg 5 Deg	28.5 Deg 15 Deg	28.5 Deg 15 Deg	0 Deg 5 Deg	0 Deg 5 Deg	0 Deg 5 Deg	0 Deg 5 Deg
<b>Location</b>	Malindi	Hawaii	Mayaguez Puerto Rico	Diego Garcia	Guam	Brazil	India
<b>Latitude</b>	3 Deg S.	19 Deg N.	18 Deg N.	7 Deg S.	13 Deg N.		
<b>Owned By</b>	Italy	USN	NASA	USAF	USN	Datalynx	Datalynx
<b>Operations Cost</b>	no cost - contributed	1 pass/day @ \$500 X 5yrs -> <b>\$900K</b>	3 pass/day @ \$275 X 5yrs -> <b>\$1.5M</b>	TBD	3 pass/day @ \$275 X 5yrs -> <b>\$1.5M</b>	3 pass/day @ \$275 X 5yrs -> <b>\$1.5M</b>	3 pass/day @ \$275 X 5yrs -> <b>\$1.5M</b>

The ground stations are valued as a percentage of maximum inverted cost (so that less is better).

### 4.4.2 Costs of Launch Vehicles

Costs of the different launch vehicles are given in the following table. The most cost effective vehicles, of course, are those which provide a direct-to-orbit inclination capability (inclination equal to latitude). These are seen to be the baseline Delta II and the Ariane 40.

Vehicle	Zenit 3SL	Ariane 40-3 (42P)	Atlas V	Delta IV- M(5,2)	Delta IV-M	Delta II
Latitude, Deg.	0	5	28	28	28	28
Inclination, Deg.	0	5 (0)	5	5	15	28
Cost, FY99 \$M	85	68 (70)	100	100	70	62

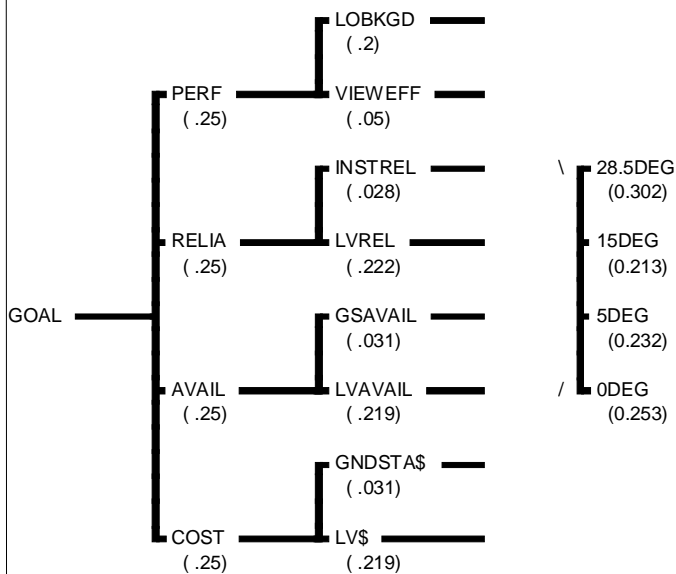
The launch vehicles are naturally valued as a percentage of maximum cost.

### 4.5 Evaluation Summary

The evaluation data is summarized in the table below. These are the measures and judgements that are input to EXPERT CHOICE.

Orbit Inclination, Deg.	28	15	5	0
Launch Vehicle Candidate	Delta II	Delta IV-M	Atlas V, Delta IV-M(5,2), Ariane 40-3	Zenit 3SL, Ariane 42P
<b>Performance</b>				
GCR Background	160	110	100	-
SAA Observing Efficiency	80%	90%	97%	100%
<b>Reliability</b>				
Instrument Risk Mitigation	Needed			Not Needed
Launch Vehicle	90	50%TBR	50%TBR 50%TBR 100%	85% 100%
<b>Costs, FY 99 \$M</b>				
Ground Stations	0.9	0.9	1.5	1.5
Launch Vehicle	62	70	100 100 68	85 70
<b>Availability</b>				
Ground Stations	Existing	Existing	Future	Future
Launch Vehicle	Approval Assured	Approval Questionable	Approval Questionable	Only for Exchange of Benefits

Figure 4-1 below shows the evaluation of alternatives in EXPERT CHOICE. Additional details appear in Appendix 4. Not surprisingly, the launch vehicle dominates all considerations of reliability, availability, and costs. The alternative (28.5 degrees) with the highest score (0.302) wins.

***Evaluating the best inclination for the GLAST mission***

Abbreviation	Definition
GOAL	
0DEG	0 degree inclination
15DEG	15 degree inclination
28.5DEG	28.5 degree inclination
5DEG	5 degree inclination
AVAIL	Availability
COST	Costs
GNDSTA\$	Costs of ground stations
GSAVAIL	Ground station availability
INSTREL	Instrument risk mitigation needed
LOBKGD	Low instrumental background due to charged particles
LV\$	Cost of launch vehicle
LVAVAL	launch vehicle availability
LVREL	launch vehicle reliability rating
PERF	Performance
RELIA	Reliability
VIEWEFF	viewing efficiency

**Figure 4-1 Evaluation of Alternatives in EXPERT CHOICE.**

Returning to the equal distribution of weights for the 4 major criteria, if one agrees with the weights and valuations of the sub-criteria, a sensitivity analysis shows the following conclusions:

- 1) There is not priority of cost that will change the selection of orbit,
- 2) The priority of availability would have to decrease from 0.25 to 0.07 before the 0 degree orbit would be selected over the 28.5 degree orbit,
- 3) Either reliability or performance needs to increase in priority from 0.25 to 0.7 before the 0-degree orbit would be selected over the 28.5-degree orbit.

## **4.6 Conclusion**

The major benefit of a low inclination orbit for GLAST is low charged particle background. Of the ways to get to a low inclination orbit, the use of foreign launch services (vehicle and launch site) is the most efficient in terms of energy and cost. However, these are not viable candidates in that they can not be procured with U.S. dollars. Getting a bigger domestic launch vehicle doesn't appear to be the answer either, because of the strength of the justification that would be needed for any additional money. Moreover, backing off to an intermediate inclination, 15 degrees, while being in closer striking distance in terms of dollars, really doesn't offer much improvement in either background or observing efficiency.

Despite the highest charge particle background and the lowest observing efficiency, the mission can be accomplished at 28 degrees inclination. Since reliability and costs are also acceptable, the baseline mission will stand.

## 5 Appendixes

### 5.1 Appendix1 Charged Particle Spectra

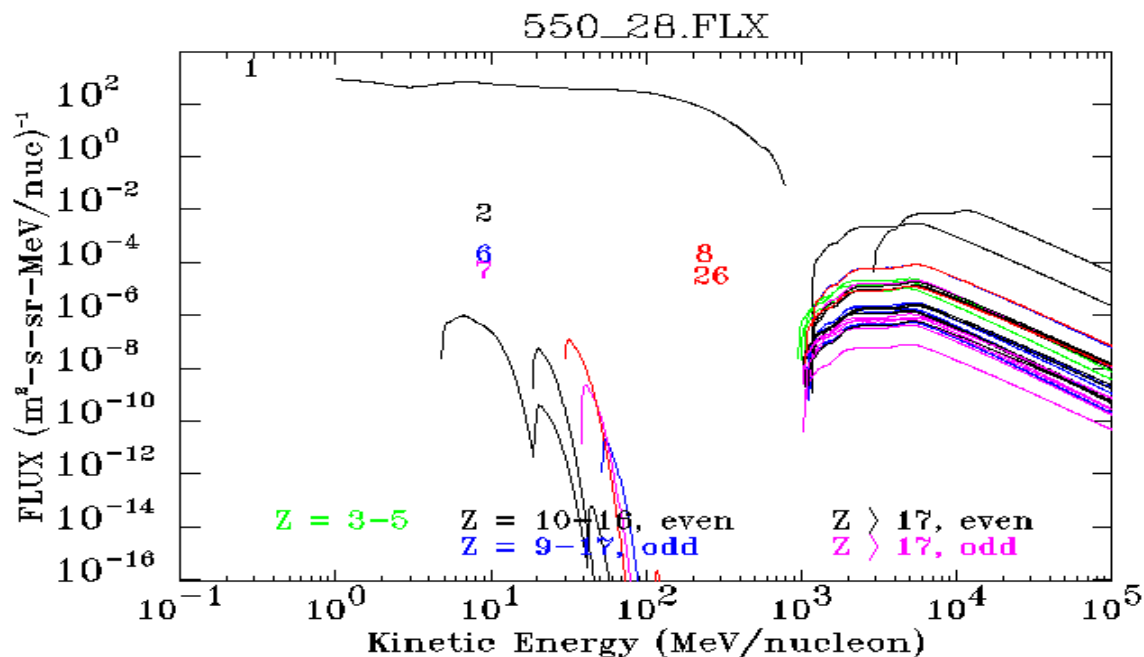


Figure5-1 Charged Particle Spectra at 28.5 Degrees

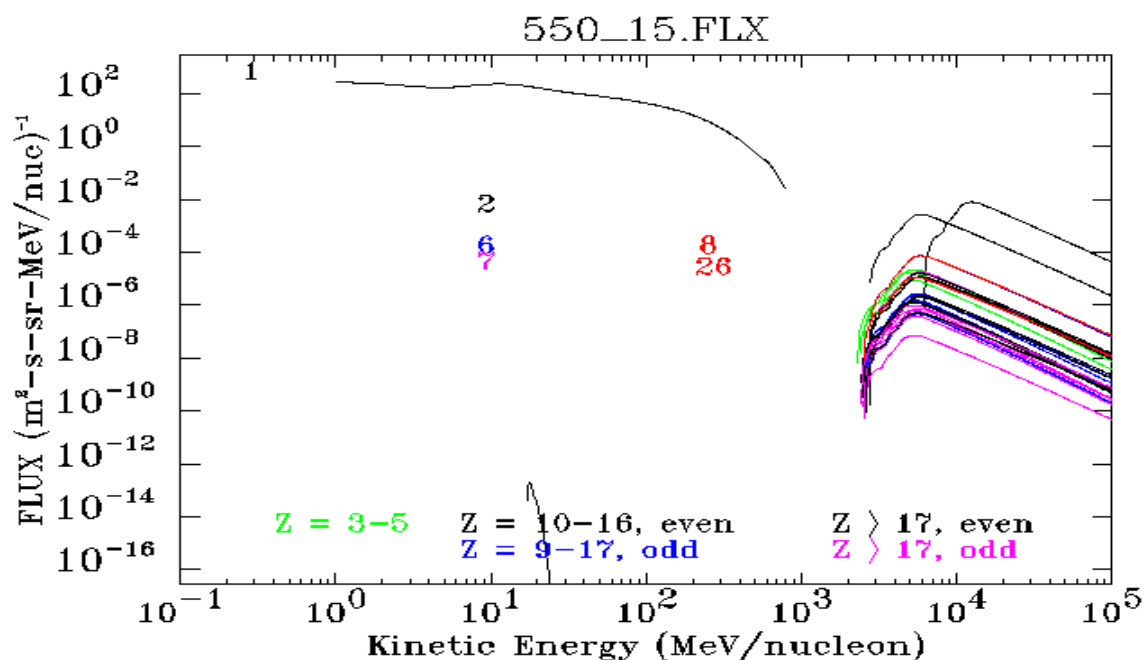


Figure 5-2 Charged Particle Spectra at 15 Degrees

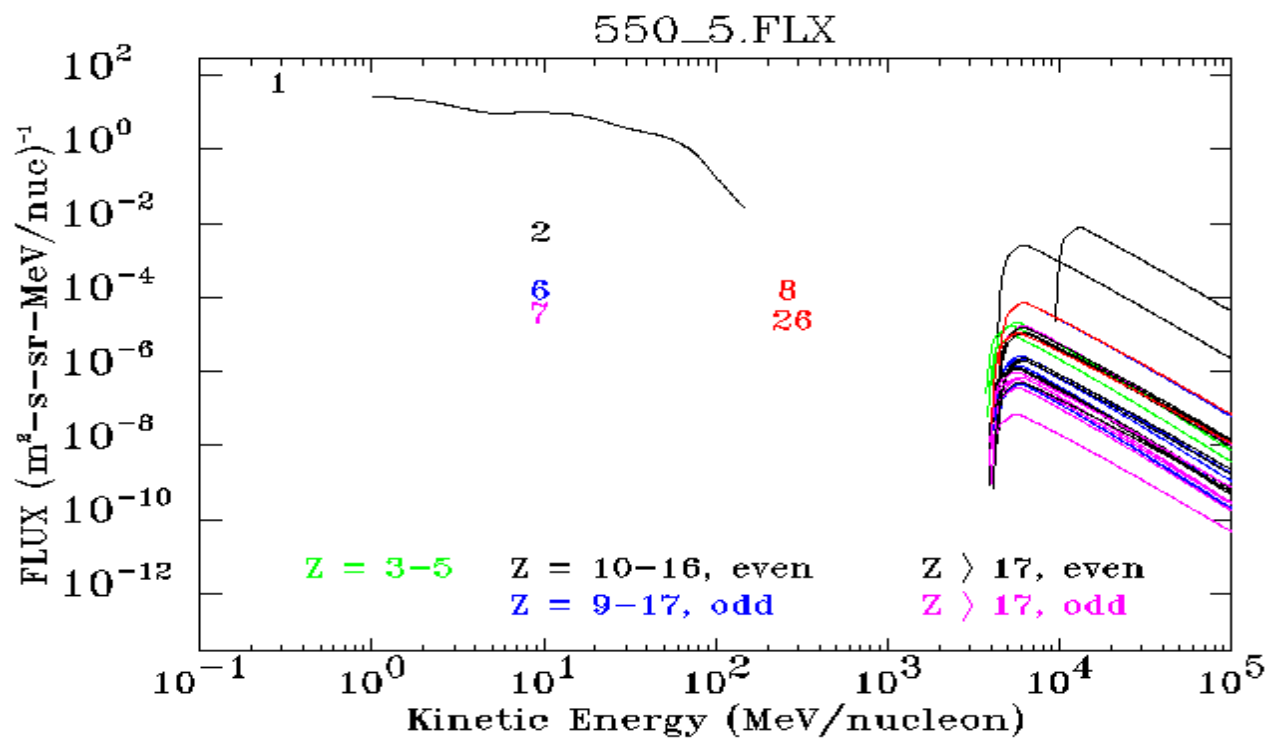


Figure 5-3 Charged Particle Spectra at 5 Degrees

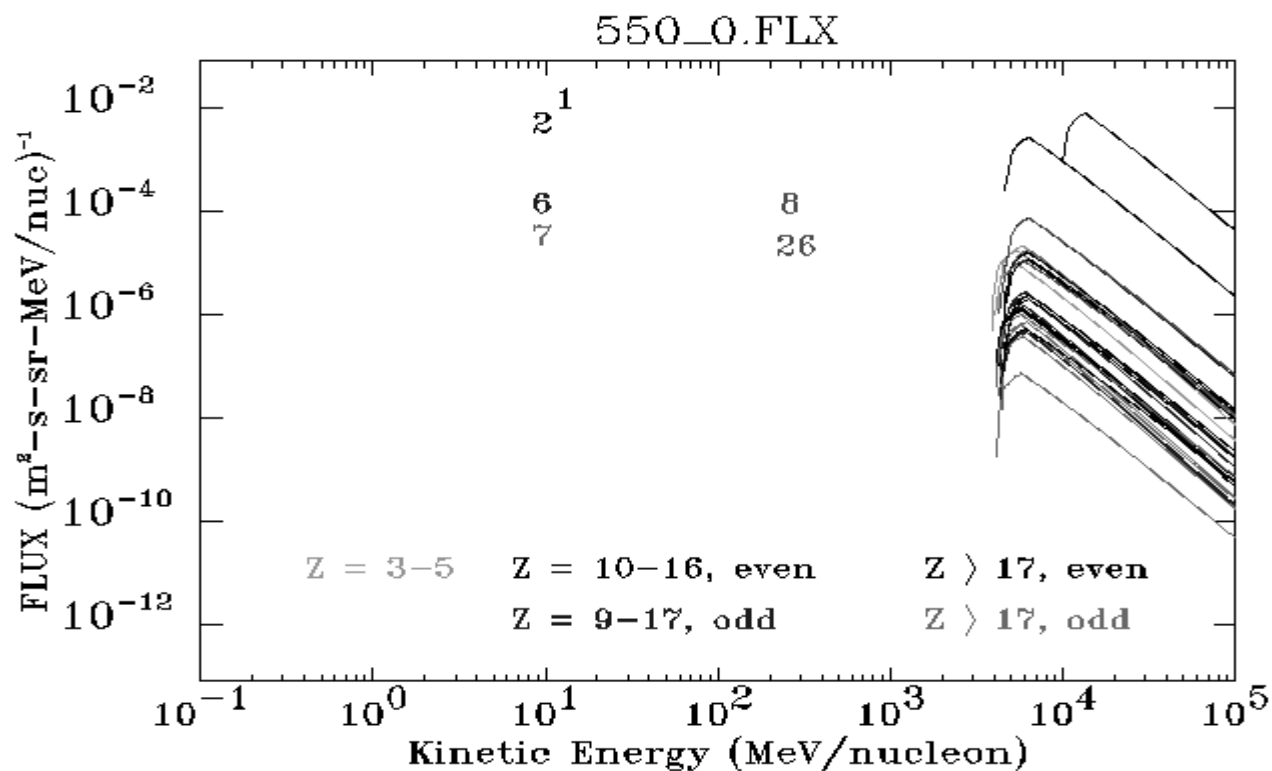


Figure 5-4 Charged Particle Spectra at 0 Degrees

## ***5.2 Appendix 2 Email Messages on Purchase of Foreign Launch Vehicle***

### **Message 1.**

Date: Mon, 14 Jun 1999 08:47:36 -0400

To: Scott.D.Lambros.1@gsfc.nasa.gov, Robert.J.Maichle.1@gsfc.nasa.gov

From: John Leon <John.Leon.1@gsfc.nasa.gov>

Subject: GLAST on ARIANE

Cc: william.e.cutlip.1@gsfc.nasa.gov, cwoodall@pop400.gsfc.nasa.gov

Scott/Bob,

Ref the note below from Frank Stone, KSC ELV Advance Mission Integration Manager. NASA can obtain a foreign launch service in exchange for science without a waiver, BUT it looks like a waiver of HR 1702 to support exchanging US currency is NOT an option. HR 1702 allows the Administrator to approve a waiver under specific exceptions, but according to the note below, NASA has reserved the approval to the President.

JLeon

>From: "Stone-1, Frank" <StoneFS@kscgws00.ksc.nasa.gov>

>To: "Leon, John" <John.Leon@gsfc.nasa.gov>

>Subject: GLAST on ARIANE

>Date: Mon, 14 Jun 1999 08:38:28 -0400

>X-Mailer: Internet Mail Service (5.0.1461.28)

>

>John,

>

>I've talked with several of the folks around here and at NASA HQ, and the

>consensus is that if you can get ESA to contribute an ARIANE launch for

>science data, i.e. as part of their participation in the mission, that's OK.

>Purchasing a launch service on an ARIANE from ESA for money, however, is not  
>an option.

>

>White House Office of Science and Technology Policy (OSTP) reserves to the

>President the ability to grant an exemption to buying only US-produced

>launch services. Currently, NASA sees no circumstances specific to GLAST or

>to any other mission that would cause us to support any such request going

>to the White House.

>

**Message 2.**

Date: Tue, 27 Jul 1999 08:13:01 -0400

To: Scott.D.Lambros.1@gsfc.nasa.gov, Robert.J.Maichle.1@gsfc.nasa.gov

From: John Leon <John.Leon.1@gsfc.nasa.gov>

Subject: RE: GLAST

Cc: Frank.Stone-1@kmail.ksc.nasa.gov, william.e.cutlip.1@gsfc.nasa.gov,  
cwoodall@pop400.gsfc.nasa.gov

Scott/Bob,

You asked me to evaluate the possibility of acquiring Sea Launch services to try and fulfill the low inclination needs of GLAST. I asked Frank Stone of KSC ELV to look into it from a contracting perspective. Frank offers the information below. Looks like there is no current capability for NASA to contract Sea Launch services. It is also worth mentioning that this service is in the \$85M ballpark according to the International Space Industry Report. We will notify you as soon as we hear of any changes with respect to Sea Launch.

JLeon

>From: "Stone-1, Frank" <Frank.Stone-1@kmail.ksc.nasa.gov>

>To: "John Leon" <John.Leon.1@gsfc.nasa.gov>

>Subject: RE: GLAST

>Date: Mon, 26 Jul 1999 14:56:55 -0400

>X-Mailer: Internet Mail Service (5.0.1461.28)

>

>John,

>

>There are two problems with Sea Launch. First, they need 51% US ownership;  
>right now Boeing owns 40%, a Norwegian company owns 20% (which is up for  
>sale), and two Russian companies own the remainder. This could be resolved  
>if Boeing (or some other US company) bought the Norwegian company's share.  
>Second, they [need] 51% US content in their product/service; right now Boeing  
>provides the fairing and the integration and launch service, which is short  
>of 51%. Sea Launch has to resolve both problems to be able to bid on NLS.  
>It's possible that they could resolve them, but we won't know until the  
>proposals come in.

>

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>

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### 5.3 Appendix 3 Orbit Maintenance Trade

According to the Delta II Payload Planners Guide<sup>5</sup>, the slope of the mass to altitude curve for the Delta 7920-10 is approximately 1 kg/km at about 4200 kg.

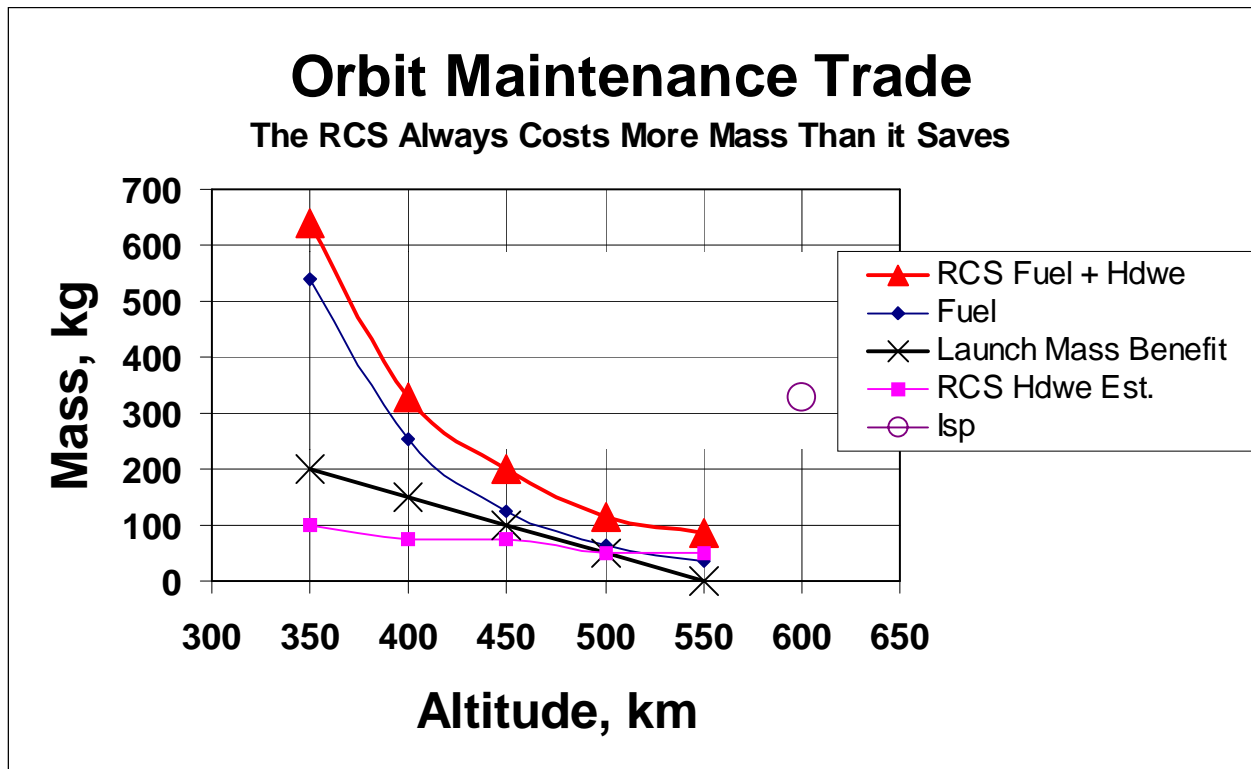
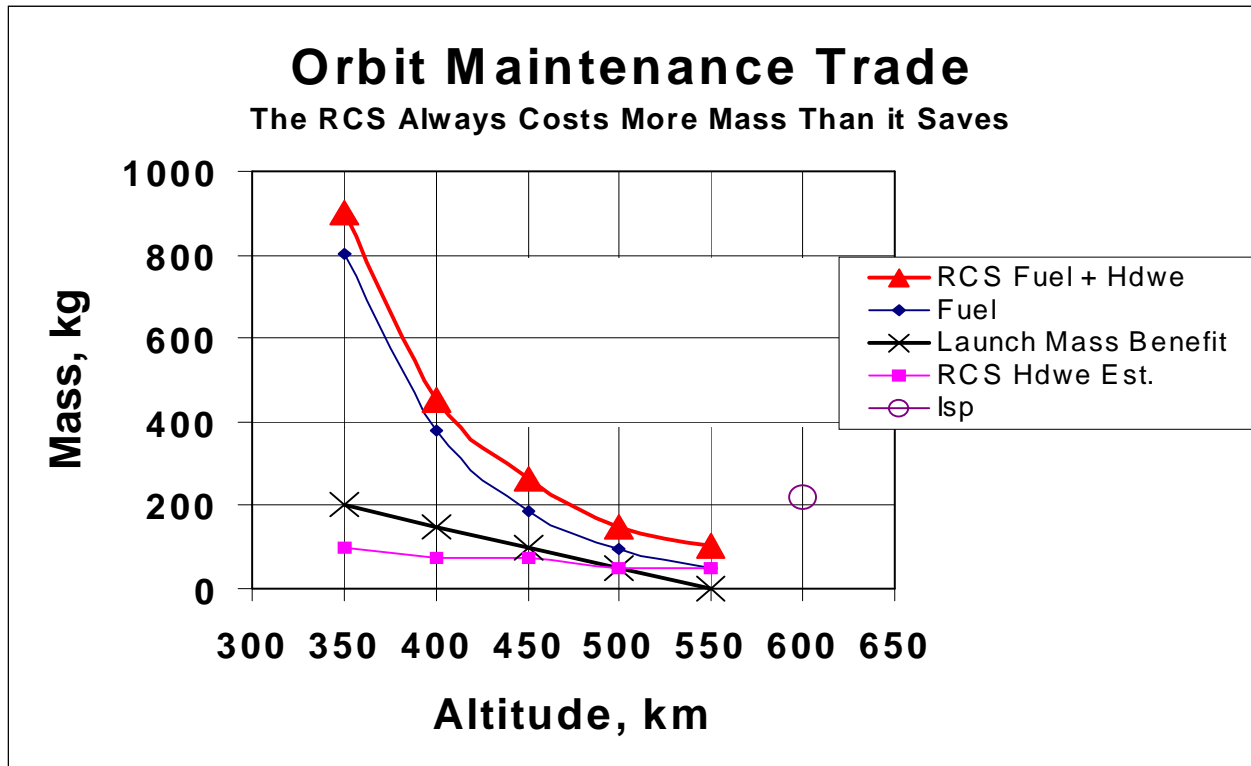
The following delta V calculations<sup>6</sup> are in correspondence with the design of the Reaction Control System (RCS) for the Tropical Rainfall Measuring Mission (TRMM). TRMM has a mission life requirement of 3 years at 350 km +/- 10 km at 35 degree inclination, circular orbit. TRMM filled its propellant tanks with 780 kg of fuel, more than enough for the 3-year mission. The mass of the RCS hardware – thrusters, plumbing, and tanks – came to 147 kg. This was discounted by a size factor for GLAST, which needs only a set of thrusters on one end of the spacecraft.

Cd	M, kg	A, m <sup>2</sup>	$\pi C_d A / m$ , m <sup>2</sup> /kg	$\Delta V_{orb} = \pi (C_d A) / M \rho a V$		g, m/s <sup>2</sup>	Isp, s
2.2	4000	16	0.027646015	$M_p = M [1 - e^{-(\Delta V / I_{sp} g)}]$		9.8	220
h, km	a, m	V, m/s	$\rho_{mean}$ , kg/m <sup>3</sup>	$\Delta V$ , m/s per orbit	$\Delta V$ , m/s per year	Mass of Propellant, kg/yr	2 Yrs
350	6728000	7697	6.66E-12	9.53E-03	5.22E+01	95.75	192
400	6778000	7669	2.62E-12	3.77E-03	2.06E+01	38.09	76
450	6828000	7640	1.09E-12	1.57E-03	8.61E+00	15.95	32
500	6878000	7613	4.76E-13	6.89E-04	3.78E+00	7.00	14
550	6928000	7585	2.14E-13	3.11E-04	1.70E+00	3.16	6
h, km	a, m	V, m/s	$\rho_{max}$ , kg/m <sup>3</sup>	$\Delta V$ , m/s per orbit	$\Delta V$ , m/s per year	Mass of Propellant, kg/yr	3 yrs
350	6728000	7697	2.18E-11	3.12E-02	1.71E+02	304.98	610
400	6778000	7669	1.05E-11	1.51E-02	8.27E+01	150.47	301
450	6828000	7640	5.35E-12	7.72E-03	4.23E+01	77.66	155
500	6878000	7613	2.82E-12	4.08E-03	2.24E+01	41.28	83
550	6928000	7585	1.53E-12	2.22E-03	1.22E+01	22.53	45
Altitude, km	5 Yr Fuel Total, kg	RCS Hdwe Est, kg	RCS Total, Fuel + Hdwe, kg	Launch Mass Savings with Altitude @ 1kg/km, kg			
350	801	100	901	200			
400	377	75	452	150			
450	187	75	262	100			
500	97	50	147	50			
550	51	50	101	0			

<sup>5</sup> <http://www.boeing.com/defense-space/space/delta/delta2/guide/delta2.pdf>

<sup>6</sup> Space Mission Analysis and Design, 2<sup>nd</sup> Edition, W. Larson and J. Wertz, Ed.

The following two charts show that the mass savings in going to lower altitude are exceeded by the mass of the system needed to maintain that altitude. The first chart is for a standard fuel, the second for a higher performance, more exotic fuel.



## 5.4 Appendix 4 Distribution of Weights in EXPERT CHOICE

### *Evaluating the best inclination for the GLAST mission*

#### Synthesis of Leaf Nodes with respect to GOAL

Ideal Mode

OVERALL INCONSISTENCY INDEX = 0.0

LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
PERF =.250				
	LOBKGD =.200			
		0DEG =.200		
		5DEG =.182		
		15DEG =.154		
		28.5DEG =.127		
	VIEWEFF =.050			
		0DEG =.050		
		5DEG =.048		
		15DEG =.045		
		28.5DEG =.040		
RELIA =.250				
	LVREL =.222			
		0DEG =.222		
		28.5DEG =.216		
		15DEG =.200		
		5DEG =.200		
	INSTREL =.028			
		0DEG =.028		
		28.5DEG =.003		
		15DEG =.003		
		5DEG =.003		
AVAIL =.250				
	LVAVAIL =.219			
		28.5DEG =.219		
		15DEG =.024		
		5DEG =.024		
		0DEG =.024		
	GSAVAIL =.031			
		28.5DEG =.031		
		15DEG =.031		
		5DEG =.004		
		0DEG =.004		
COST =.250				

***Evaluating the best inclination for the GLAST mission***

	LV\$ =.219		
		28.5DEG =.219	
		5DEG =.199	
		0DEG =.194	
		15DEG =.136	
	GNDSTA\$ =.031		
		28.5DEG =.031	
		15DEG =.031	
		5DEG =.019	
		0DEG =.019	



Abbreviation	Definition
GOAL	
0DEG	0 degree inclination
15DEG	15 degree inclination
28.5DEG	28.5 degree inclination
5DEG	5 degree inclination
AVAIL	Availability
COST	Costs
GNDSTA\$	Costs of ground stations
GSAVAIL	Ground station availability
INSTREL	Instrument risk mitigation needed
LOBKGD	Low instrumental background due to charged particles
LV\$	Cost of launch vehicle
LVAVAIL	launch vehicle availability
LVREL	launch vehicle reliability rating
PERF	Performance
RELIA	Reliability
VIEWEFF	viewing efficiency